The new growth theories: a survey of theoretical and empirical contributions

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Historical Social Research, Vol. 25 – 2000 – No. 2, 3-22

The New Growth Theories
A Survey of Theoretical and Empirical Contributions

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Abstract: The debate concerning the various determinants of economic growth has attracted considerable attention, both through the importance of its implications in terms of economic policy and through the number of theoretical and empirical analyses that it has engendered. This being so, the aim of this article is (I) to undertake a critical reading of the contribution of the "new growth theories" and (11) to review the empirical assessments of its endogenous nature.

Introduction

The movement of the production potential of the industrialised nations over long periods of time is at the centre of the very latest economic debates. This preoccupation is far from new. The classical economists were already concerned about how to increase welfare by increasing growth.

The subject remained controversial after Word War II, with the theoretical debate on the long-term stability of market economies. However, through Solow's economic-growth model (1956) neo-classical thinking gradually exerted its power. Its reasoning is clear and it also explains numerous aspects related to economic growth which are summarised perfectly in Kaldor's six "stylised facts" (1963). At the same time-perhaps paradoxically-scientific interest in work on growth and economic fluctuations disappeared. There were two main reasons for this. Firstly, the short-sightedness of economists whose attention was centred almost exclusively on the study of short movements and secondly,

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the comparative weakness of theoretical models incapable of solving the aspects that remain unexplained by the different theories of growth.

This partially explains why the post-war neo-classical models are unsatisfactory. Indeed, in the long run, they only account for economic growth by involving exogenous factors (except for Ramsey's model (1928) that was rediscovered very recently) and in this case the technical progress achieved without cost outside the economic system. In addition, Solow's reference model does not provide any way of explaining the divergence in growth rates at the international level, as with the idea of long-run equilibrium, all countries should Progress at identical, exogenous rates of technical progress. Similarly, it should be noted that the hypothesis of the systematic existence of a negative correlation between income level and economic growth rate is not based on any satisfactory empirical verification. Finally, nothing really corroborates the convergence hypothesis, that is to say the transfer of capital from the richest to the poorest countries.

However, the work of Lucas (1988) and Romer (1986, 1990) attracted attention, and the 1980s marked a renaissance of the neo-classical theory of growth. The prime objective was to go beyond the weakness of the old theoretical models. The aim was also to answer new questions:

1) What are the determinants of sustainable economic growth? Can technical progress alone increase social welfare or can capital accumulation also lead to a permanent increase in per capita income? What are the factors of production that engender sustainable economic growth: physical capital, environmental capital, human capital or technological knowledge?
2) What are the mechanisms that guarantee growth over a long period for a market economy?
3) Finally, what is/are the market structure/s within which economic growth can be achieved?

Strengthened through these questions, the debate on the determinants of the economic growth process has attracted considerable attention, both in the importance of its implications in terms of economic policy and in the number of theoretical and empirical analyses that it engendered. Thus, the argument that endogenous growth models account for long-term economic growth is often put forward. The models affirm that the introduction of a new accumulation factor, such as knowledge, will induce self-maintained economic growth. However, in spite of numerous theoretical developments, attempts at empirical verification have run up against serious methodological difficulties.

The aims of this article are therefore (I) to undertake a critical reading of the theoretical contribution of the "new growth theories" and (II) to review the empirical assessments of its endogenous nature.

1. Formal Aspects of the Theories of Endogenous Growth

The "new growth theories" developed since the end of the 1980s are Seen by many as a decisive step forward compared to Solow's standard exogenous growth model (1956). The poorly matching hypothesis of the exogenous nature of technical progress is abandoned in order to see growth as a truly endogenous process. These theories are constructed around the central idea that factor returns no longer decrease when it is accepted that components other than physical capital (such as human capital) exist and can display endogenous accumulation. This endogenous character of growth may also be seen if we accept the existence of positive externalities that "compensate" the falling marginal productivity of physical capital. These externalities originate in activities such as research and development, the dissemination of knowledge or the construction of public infrastructure. In short, growth is a self-maintaining process taking place at a constant rate because the returns of the accumulation factors are constant.

Endogenous growth theories therefore have the common aim of understanding the long-term growth of per capita income and describing it as the product of the economic system. The differences in development between nations and the non-convergence observed would thus have a theoretical explanation in the dependence on initial conditions. It should be noted here that the generic term "endogenous growth" covers a host of models. Indeed, these theories are characterised by the great variety of the sources of growth chosen: investment in physical capital, human capital, public capital, learning by doing, division of labour, research and technological innovation. These sources have long been identified by economists, and in particular by Adam Smith (1776), but endogenous growth theories formalise them for the first time and thus make it possible to gain a better view of their effects. From this point of view, the analyses below are aimed first of all at presenting the most simple endogenous growth model – the AK model – and then at stressing the Formation of human capital and research and development activities as the driving forces (in the form of accumulation factors) of endogenous growth. The introduction of other accumulation factors such as learning by doing or public capital is covered in a common, summary section (we do not claim to make an exhaustive presentation of work on endogenous growth). As the principles and hypotheses enabling the achievement of self-maintained growth are common to all the models, full descriptions are not necessary.

1. The AK model: Rebelo (1991)

The AK model is the most simple version of the endogenous growth models. This formalisation eliminates all the fixed factors (the factors available in the same quantities during each period, such as land, raw materials, labour, etc.) that are not reproducible and therefore cannot be accumulated. The fact that they are not taken into account in the production of capital goods makes it possible to achieve endogenous growth in spite of the absence of increasing returns to scale (the hypothesis is that these remain constant) or externalities. The essence of endogenous growth then resides in the use of reproducible factors (that can be accumulated) alone. This central hypothesis makes it possible to affirm that capital returns are constant. The production function is then summarised by the following expression:

$$Y=AK$$

A is a positive constant, a exogenous scale parameter indicating the level of technology, K is a generic term describing capital including human capital, the stock of knowledge, financial capital, etc. Human capital is subject to accumulation and substitutes the labour factor (which is by nature not reproducible). Capital is therefore a composite component, an aggregate incorporating all the accumulation factors. The non-decreasing returns allow self-maintained growth. This fairly simple model makes it possible to understand the formal roots of endogenous growth.

2. Education as the driving force of self-maintained economic growth

The analyses by Lucas (1988) and then by Azariadis and Drazen (1990) put the sphere of education in the heart of the growth process by using a "subjective" conception of knowledge[1]. Knowledge is a rival good and its use is exclusive[2]. It is incorporated in persons as human capital.

Lucas ' model (1988)

Lucas analyses the individual decisions aimed at acquiring knowledge, their consequences for the productivity of individuals and for economic growth as a whole. He considers human capital as an alternative and a complement to technical progress in its function as a driving force for growth. He defines it as the "general skill level", this being the individual's set of physical, intellectual and technical capabilities. Human capital is rival and exclusive because it is incorporated in individuals. A production sector and an education sector coexist in

1 The conception of knowledge is qualified as being subjective, i.e. incorporated in individuals, as opposed to an objectivised conception, where knowledge is materialised in equipment.
2 Its use by one agent excludes use by another individual. Its owner can use technical or legal systems to prevent others from using it.

his model. The first produces goods from physical capital and part of human capital, which according to Lucas can be accumulated, with non-decreasing and at least constant marginal productivity. In the second sector, human capital forms and accumulates through itself, with the part of human capital not used in the production sector. The individual educates himself using his time and part of the skills that he has already acquired.

An individual thus devotes his non-leisure time to production or education activities. This allocation affects his productivity and his level of human capital h. Thus, if N workers considered as identical agents possess the Same skill level h and devote a fraction u of their non-leisure time to current production, the remaining part 1-u is allocated to accumulation of human capital. The effective workforce, that is to say the sum of human skills devoted to present production, is written as follows:

$$L^e = uhN$$

Production is a function of total physical capital K and of effective work: Y = F(K, L^e). Lucas identified two effects of human capital. The first is internal and affects the productivity of the individual who has gained skills, whereas the second is considered as external insofar as human capital accumulation by an individual contributes to improving the productivity of others. This external effect is not taken into account in the time allocation decisions taken by economic agents. This externality in the production of the good represents the average and not the total human capital of individuals participating, noted h_a It represents the idea that individuals will become more productive if they are in contact with trained, qualified persons and that this will result in enhanced collective skills thanks to the exchange of ideas and practices. At equilibrium, as all individuals are identical, the average skill level h_a becomes simply h.
In the production section, production good technology is written as follows:

$$Y(t) = N(t)c(t) + \dot{K}(t) = AK(t)^{\beta}[u(t)h(t)N(t)]^{1-\beta}\, h_a(t)^{\gamma}$$

c(t) is per capita consumption. Technology level A is assumed to be constant. Externality is not necessary to obtain endogenous growth, since an accumulation input-human capital-with non-decreasing returns is substituted for the labour factor in the production function, thus making positive growth possible. Lucas uses this demonstration to account for the dependence of the per-capita income path on the initial conditions and hence the persistence of international differences in development, and the non-convergence of economies and other phenomena such as population movements (which, however, are outside the scope of this discussion).

Human capital produces itself in the educational sphere. The effort devoted to the accumulation of human capital 1-u(t) should be related to the rate of variation of its level h(t). Achieving exogenous growth, without taking into account the existence of a possible externality, requires that the returns of accumulation of human capital do not diminish. The expression of $\dot{h}(t)$ below does not induce decreasing returns of human capital stock h(t):

$$\dot{h}(t) = h(t)\varphi[1-u(t)]$$

As knowledge accumulation is assumed to be linear (which is questionable because one might support the hypothesis that the stock of knowledge displays threshold effects), it displays non-decreasing marginal returns that enhance unlimited growth. Encouragement to invest in human capital is non-decreasing (function φ is assumed to be non-decreasing). An increase in the stock of human capital requires an identical effort whatever the level previously attained. In substance, the accumulation of human capital intrinsically displays factor returns that are at least constant in comparison with the level previously attained. In relative terms, human capital increase is independent of existing human capital. In one hour of training, a child learning to read makes less Progress in tems of absolute value than an engineer (whose stock of human capital is obviously considerable) learning new techniques. However, the child makes perhaps as much if not more progress in relative value, in such a way that the marginal productivity of human capital is always at least constant as one invests in education. This in an inherent feature of an intangible good, as stressed by Lucas. The human capital growth rate thus appears to be independent of the initial human capital level[3]:

$$\dot{h}(t)/h(t) = g_h = \varphi(1-u(t))$$

To prevent the stock of human capital of households from remaining constant, Lucas assumes that the $\dot{h}(t)$ equation applies to a representative household with an infinite lifetime. This hypothesis makes it possible to affirm that human capital accumulation does not display decreasing returns. Clearly, this formulation no longer applies when one considers an individual whose lifetime is limited and whose human capital disappears with him when he dies. The initial level of each new member becomes proportional (and not equal) to the level already attained by the older members of the family. The optimal growth path corresponds to choices of consumption flow and the time spent working (or studying) that maximise the inter-temporal use of agents while respecting the constraints of physical and human capital accumulation. Assuming a closed economy and a population rising at a fixed rate n, the preference of the representative household is expressed by the isoelastic utility function below, in

[3] "A given percentage increase in h(t) requires the Same effort, no matter what level of h(t) has already been attained." Lucas (1988, p. 19).

which the variable ρ represents a preference rate for the present and σ the constant inter-temporal elasticity of substitution:

$$\int_0^\infty e^{-(\rho-n)t}\left[\frac{c(t)^{1-1/\sigma}}{1-1/\sigma}\right]dt$$

Dynamic optimisation is used to solve the maximisation program and to determine the value of g, the common growth rate of consumption, capital and product:

$$g = g_k = (1-\beta+\gamma)g_h/(1-\beta) = \varphi(1-\beta+\gamma)(1-u)/(1-\beta)$$

The engine of economic growth is thus the effectiveness of accumulation of human capital, φ, the scale of its effect on production as on externality, γ, and the fraction of time available allocated to knowledge accumulation (1-u). The source of growth thus resides in unlimited accumulation of human capital *h* whose returns do not diminish. In other words, the linear growth of *h* during each period accounts for the potentially unlimited nature of economic expansion. The existence of the externality measured by parameter γ is not essential for achieving positive growth, it just accelerates it. However, its presence leads to differentiating between balance and optimum and to taking into account the inadequacy of investment in education, justifying public education policies. Nevertheless, the hypothesis chosen for function φ brings up a number of questions. Indeed, what arguments form the basis for Lucas' affirmation that human capital accumulation displays non-decreasing returns? Is not Uzawa's hypothesis (1965) that this function is a decreasing one just as realistic? Endogenous growth is therefore based on a very particular hypothesis that can easily be called into question. The level of growth and not its rate would depend on the effort made in education. In short, in contrast with Lucas' assumption, endogenous growth would seem to be based more on the existence of externalities resulting from human capital accumulation than on the non-decreasing returns of the latter.

The models proposed by Lucas and by Uzawa finally seem very similar, with the noteworthy exception pointed out by Mino[4] that Uzawa refuses to consider the hypothesis of externalities of the "Marshall" type in human capital accumulation. In other words, he does not envisage the hypothesis of increasing returns to scale. However, Lucas mentions the possibility of unbalanced growth and, *a fortiori*, that of a situation that is not optimal with regard to the Pareto's criterion. Thus the major difference between these two models resides in the nature of the factors and in the hypothesis put forward with regard to the

[4] "Although modeling strategies of Uzawa (1965) and Lucas (1988) are based an similar ideas, there are important differences between their discussions. First of all, Lucas introduces Marshallian externalities of human capital, while Uzawa ignores externalities." Mino (1996, p. 227).

education function φ In Lucas' model, human capital replaces the labour factor. It becomes an accumulation factor inducing self-maintained growth. The function φ is assumed to be non-decreasing, enabling limitless accumulation of the human capital that is the source of endogenous growth. Meanwhile, Uzawa retains the "classical" notion of the non-reproducible labour factor. *A(t)* can be modified instantaneously and bears no trace of the past. The function φ still has decreasing returns and because of this the growth rate of the economy still depends on exogenous features such as the rate of growth of the working population, the Speed of technical progress or the improvement of labour efficiency.

Lucas' model has served as reference for numerous analyses studying the impact of investment in education on economic growth. Chamley's view (1993), for example, is the same as Lucas'. The conception of extemalities, however, does differ. Lucas is of the opinion that they affect stocks of human capital (the production goods). Chamley holds that they affect flows of human capital (the production of human capital in the case of researchers working together). This changes human capital accumulation:

$$\dot{h} = h_t \varphi(u_t, \bar{h}_t)$$

in which $\bar{h}$ represents the average level of human capital. Chamley's conclusions concerning the importance of substantial investment in human capital as the main source of growth are nevertheless identical to those of Lucas.

Caballé and Santos (1993) do not consider the existence of externalities. They assume that physical capital can be an input in the production of human capital. Human capital accumulation is then written as follows:

$$\dot{h}(t) = \varphi[\frac{(1-v(t))K(t)}{N_0}, (1-u(t))h(t)] - (v+\theta)h(t)$$

The education function φ thus becomes a growing function of the two types of capital, in which *v(t)* represents the fraction of physical capital devoted to the production of consumer goods, *u(t)* is the proportion of human capital allocated to the production sector, *v* is the growth rate of human capital, θ is the constant depreciation rate of human capital and N_0 is the initial state of the population variable. Human capital remains the key factor in endogenous growth. Indeed, from a given equilibrium onwards, the injection of human capital leads the economy to another state of equilibrium with higher levels of physical capital and consumption. Likewise, an increase in physical capital engenders a process of human capital accumulation that enhances growth.

The fact that the increase in the average level of human capital is linear in these various models raises a number of questions. Indeed, might it not be possible that the accumulation of human capital by a representative individual may depend on the level already attained by his/her parents, the average level in the economy or the individual's initial level? Moreover, is not the hypothesis of an individual with an infinite lifetime too "risky" and an oversimplification?

In any case, by eliminating it, Azariadis and Drazen (1990) demonstrate that the accumulation of human capital displays threshold effects justifying the possibility of multiple equilibria and strong differences between the per capita growth rates of national economies.

The model of Azariadis and Drazen (1990)

Azariadis and Drazen propose an endogenous growth model with imbricated generations in which human capital is the engine of growth since its accumulation displays increasing social returns to scale. Individuals are all identical, and their lives can be divided into two periods. The first is the period of training and work, and the second is devoted to work alone (the time invested in education during their youth is converted into subsequent quality of labour). At the end of their life, they involuntarily bequeath part of their human capital to their descendants. An individual borm at time *t* inherits an amount of human capital h_t, and devotes part of his time u_t, to improving the quality of his labour; the effective labour units that he provides in *t+1* depend on these two components:

$$h_{t+1} = h_t \varphi(u_t, h_t)$$

Function φ representing education production technology, displays growth, is concave and displays decreasing returns. Inherited human capital exercises a positive external effect on the effectiveness of teaching. Assuming that education only yields financial benefits, the individual chooses his level of education and thus the amount of his investment in human capital with the sole aim of maximising the updated value of the wages (those of both periods). As he is not altruistic in his optimisation calculation, he does not take into account the heritage in human capital that he will bequeath to his descendants. This introduces an inter-generational externality.

Production involves two factors of production, capital and labour. In this context, the latter becomes a factor in accumulation thanks to efforts on education and inter-generation inheritance. Its formal expression is as follows:

$$L_t = (1-u_t)h_t + h_t$$

The first term represents the labour supply consisting of young people, and the second that consisting of old people who depend on the effort made an education during the previous period, together with the average human capital obtained and bequeathed by the preceding generation. The labour supply increases continuously, no longer for exogenous reasons such as population growth but as a result of endogenous causes related to investments in human capital. If no effort is made in education, human capital remains constant from one generation to the next and is representative throughout the life cycle of individuals. Economic growth would be nil in this case. A strictly positive effort is required with regard to education in order to obtain growth. The main condition for the achievement of growth is a high rate of investment in human capital in relation to per capita income[5]. The inter-generation externality combined with positive investment in education allows the unlimited growth of average human capital and hence strong economic growth. These two features account for the differences in development between nations. Those whose human capital does not attain a sufficiently high quality threshold remain poor, in a situation referred to as the underdevelopment trap. The "take-off ', as used by W. Rostow [6], would therefore depend on the level of human capital present in the economy and on the educational effort that is made to increase it.

Following this work, Saint-Paul and Verdier (1993) construct a non-overlapping generation model. They assume the existence of an infinite number of generations each living for one period. The total population of each generation is constant at one unit. The authors then stress the importance of redistribution in the form of public education, i.e. education provided in an egalitarian manner and funded by a tax proportional to incomes. This form of redistribution induces an increase in the level of human capital in the economy and also produces supplementary distribution of incomes without any harmful effects on growth. Public education appears as a component of intra-generation redistribution and as an activity that creates human capital, a source of growth. Individual human capital has an inherited component and a component derived from public education, in such a way that more education of individuals results in stronger growth because human capital increases from one generation to the next.

The stock of human capital of an individual *i* at *t+1* is written as follows:

$$h_{it+1} = (1-z)\delta h_{it} + g_t$$

The proportion of time (1-z) devoted to the passing on of human capital from an individual to his descendants is assumed to be constant and exogenous. hit the human capital of the dynasty i at t, gt, is the level of public education and δ is the coefficient of productivity of the heritage of human capital. As individuals are altruistic, this coefficient is greater than one, inducing a cumulative effect on the passing on of human capital and thus enabling perpetual positive growth. Public education enhances this growth process and the tax that funds it does not engender any distortion.

In a general manner, the various models presented affirm the importance of human capital in the growth/development process. Moreover, the probable

[5] "Another testable implication of this framework is that, keeping all other things constant, a high ratio of human investment to per capita income is a necessary condition for sustained growth at a rapid rate." Azariadis and Drazen (1990, p. 524).

[6] In the The Stages of Economic Growth, Rostow (1960) maintains that the economic development of societies consists of five stages: traditional society, conditions prior to take-off, take-off, movement towards maturity and the mass consumption era.

existence of externalities-either inter-generational or contemporaryresulting from the accumulation of human capital induces private underinvestment in human capital, putting public education policies in the Spotlight. The opportunity and impact of public subsidies on human capital accumulation is of obvious interest and form a research field that has been explored by numerous authors, among others Nerlove *et al*. [7] However, the conception of knowledge used in these models raises a number of problems. Indeed, if one removes the hypothesis of an infinite lifetime of individuals from a model of the Lucas type, human capital can no longer display unlimited growth; its accumulation becomes bounded by the fact that an individual can only devote a finite number of years to the gaining of skills and that these skills disappear with him when he dies. More generally, the Interpretation of knowledge as a rival good is contrary to the idea of the dissemination of knowledge. Endogenous growth is therefore based on the hypothesis that the education function (φ) is non-decreasing. However, this hypothesis can easily be called into question. Indeed, the fact that human capital depreciates in time has to be taken into account. In addition, knowledge is not limited to that possessed by individuals but is concretised in technology.

In a model proposed in 1990, Romer provides a framework for analysis making it possible to apprehend this other dimension of knowledge and hence to gain another view of endogenous growth.

3. Knowledge produced by research and development: Romer's model (1990)

Romer extends and goes beyond the approach to technical progress that is part of the "capital generations" models of Johannen (1959) and Solow (1957) to Show how technology can induce self-maintained growth. Technology is considered as targeted knowledge, a Set of instructions (making it possible to manufacture capital goods) which, in contrast to Lucas' vision, is not part of the individual. Its growth is not linked to the life of the individual and can hence be unlimited. Better trained individuals can develop a larger number of

[7] Nerlove, Razin, Sadka and Von Weizsäcker (1990, pp. I-20). These authors analyse the effects of fiscal policy an the accumulation of human and physical capital. A general tax an returns from capital and labour discriminates between investments in human capital by exerting a double distorsion. As the tax is levied both an main investment and an its returns represented by individual gains in wages, it strongly reduces the returns from this type of investment and discourages it. They conclude that because of the presence of externalities in the accumulation of human capital, the enhancement of growth requires an optimum policy that would consist of taxing the returns from human capital and subsidising investments in human capital.

innovations, an endogenous source of technical progress. Thus, the greater the stock of human capital, the stronger growth will be [8].

This conclusion is based on three postulates forming the Basis for discussion: (I) technical progress is central to growth; (II) it is the result of voluntary decisions taken by individuals who respond to market incitements and seek to maximise profit and utility, making it endogenous, (III) the procedure for the implementation of technological innovations is intrinsically different from the modes of use of other economic goods. Technology is neither a conventional good nor a public good but a non-rival good for partially exclusive use. Once the cost of a new set of instructions has been Borne, the latter can be used without limit at no additional cost. Technology induces only fixed costs. It is difficult to reconcile these three postulates with competitive equilibrium, since competition tends to become monopolistic. The production function can then be written with the expression below, in which A represents a non-rival input and x is a rival input: $F(A, x)$. Homogeneity of degree orte is not plausible as it is not necessary to duplicate non-rival goods to double production. As A is productive, the production function becomes non-concave in such a way that remuneration for marginal productivity is no longer possible.

The general principle of the model consists of defining technology as a variable depending directly on the level of formation of human capital. Thus, the impact of human capital-and therefore of knowledge-on growth is analysed through its indirect effect on the production of innovations.

Romer considers a three-sector economy with (I) a research sector (where technologies are produced), (II) an intermediate-goods production sector and (III) a final-goods production sector. Four inputs can be used in production: physical capital, K, measured in units of consumer goods, labour, L, measured by the number of persons, human capital, H, defined by the number of years of education or training (a rival component with exclusive use of knowledge), and an index of the technology level, A, a non-rival component that can grow without limits because its existence is not linked to that of the individual. Each new knowledge unit is assumed to correspond to the design of a new good. A is therefore defined by the number of existing products. Thus knowledge is no longer the production of education but of research.

Population and labour supply are both assumed to be constant. The stock of human capital and the fraction supplied to the market are fixed a priori, i.e. H and L are given. However, apprehending human capital as a fixed exogenous factor (as orte would do for land) may seem debatable. Assuming that physical capital can be accumulated as saved production means admitting that it is produced in a separate sector which possesses the Same technology as that of consumer goods. Not consuming becomes the equivalent of shifting resources from the final-goods sector to the capital sector. In addition, the hypothesis

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[8] "The main conclusions are that the stock of human capital detennines the rate of gowth, that too little human capital is devoted to research in equilibrium. ..... Romer (1990, p. S71).

according to which the research sector possesses an intensive feature with regard to human capital and knowledge excludes labour and capital from this sector. The activity of the sector combines human capital and the pre-existing stock of innovations to produce new technologies or knowledge (new flux of innovation: $\dot{A}$). $\dot{A}$ is the sum of the production of all researchers, the number of new capital goods designed:

$$\dot{A} = \kappa H_A A$$

A is the knowledge stock available (technology level index), H_A is the quantity of labour assigned to research (number of researchers) with $H_A + H_Y = H$ (H_Y is the proportion of human capital assigned to the production of final-goods), and κ is a scale and productivity parameter. The production of designs by a researcher is a deterministic, continuous function of inputs. If researcher j possesses an amount of human capital H_J, and if he has free access to the total stock of knowledge A (non-rival input), his production will be $\kappa\ H_J A$. The growth of A increases the productivity of human capital. The flux of new knowledge $\dot{A}$ represents the sum of the production of all researchers. The production function is linear in H_A and in A respectively when the other factor is fixed. The linearity of A makes self-maintained growth possible. However, as Romer points out[9], this is more an assumption than a result of the model.

Each new discovery enables the production of a new capital good in the second sector. This production implements the designs developed in the research sector and the output (measured in units of final goods) saved. The evolution of total capital K is defined as the non-consumed fraction of production.

$$K = \eta \sum_{i=1}^{A} x_i$$

The capital goods produced are then usable as inputs in the production of final goods. The stock of capital is represented as the sum of qualitatively different capital goods. They are not perfect substitutes (logic of models with generations of capital). The creation of one unit of each type of producer requires η units of saved consumption. Total capital increases with the sum of the production of final goods saved, in which x_i; is the available quantity of each type of capital i. In this sector, there is a distinct firm for each capital good i. The research and production departments are treated separately for reasons of simplification. The former supplies a design at a given price and the latter produces a differentiated capital good (which is assumed not to depreciate) that it rents and does not sell to the firm producing consumer goods. The production of final goods uses labour L, a fraction of the human capital devoted to production H_Y and all the capital goods available. Its output is consumed or saved as new capital.

9 "Linearity in A is what makes unbounded growth possible, and in this sense, unbounded growth is more like an assumption than a result of the model.", Romer (1990, p. S84).

$$Y(H_Y, L, x) = H_Y^{\alpha} L^{\beta} \int_{i=1}^{\infty} x_i^{1-\alpha-\beta} di$$

Returns to scale are constant. Production is described as the result of a single, competitive enterprise.

According to Romer, technological knowledge is a good that can be used by anybody, in such a way that each supplementary unit of human capital devoted to research increases not only the level but also the growth rate of technological production. Production in this sector displays increasing factor returns insofar as all past discoveries benefit all researchers and increase their productivity. Research has a positive externality. Indeed, more new capital goods are developed when larger amounts of human capital are devoted to research. The greater the range of capital goods, the greater the productivity of an engineer working in the research sector. An engineer working in the research sector today has the same human capital as one operating a century ago (human capital being measured in years of education, which may seem restrictive) but is more productive as he or she benefits from the accumulated knowledge of the past 100 years. Research induces positive external effects. An innovation increases the productivity of all future researchers whereas its market price does not incorporate this "benefit". In fact, the existence of positive externalities is linked to the process of dissemination of knowledge.

The heart of the model thus lies in the allocation of human capital to Innovation and production activities on the one hand and in product allocation to consumption and Investment on the other. The innovation determines the growth rate of the product while physical capital affects the level of growth. Thus, the total quantity of human capital and its average level per individual determine the economic growth rate. Growth increases with the amount of human capital allocated to the research sector The accumulation of knowledge is the engine of growth and an economy devoting a large proportion of its human capital to research will tend to grow faster than another. These conclusions stem naturally from the idea that all the variables of the model grow at an identical, constant rate *g*:

$$g = \dot{C}/C = \dot{Y}/Y = \dot{K}/K = \dot{A}/A = \kappa H_A$$

Production grows at the same rate as A when one considers L, H_Y and $\bar{x}$ (the common quantity of each capital good supplied). Capital K increases at the same rate as A because the total use of K is $A\ \bar{x}\ \eta$ (by definition of K). Thus, Romer reaches the conclusion that too little human capital is devoted to research[10] and that an appropriate economic policy would consist of subsidising

[10] "There are two reasons to expect that too little human capital is devoted to research. The most obvious reason is that research has positive external effects." Romer (1990, p. S96).

this activity. Subsidising the accumulation of human capital would be only a second-rate policy insofar as this accumulation does not necessarily give decreasing returns, as supposed by Lucas. However, Romer's conclusions are also based on the "arbitrary" hypothesis of the linearity of A. Likewise, his conception of the research sector does not include a number of real features. He omits the exogenous (to the economy) components of the research process and does not mention the uncertainty surrounding research projects. In addition, as was remarked by Solow (1994)[11], it is just as pertinent to affirm that an Innovation only creates an increase in the absolute value of A and not a proportional increase of A, an increase in resource allocation to the research and development sector would no longer result in an increase in the growth rate of A but just in a single increase in productivity.

4. The other sources of endogenous growth: *learning by doing* and public infrastructure

Romer (1986) uses the framework defined by Arrow (1962) to eliminate the decreasing returns trend by assuming that the creation of knowledge is an unintended by-product of Investment. A firm that increases its stock of physical capital simultaneously leams how to produce more efficiently. This positive effect of experience on productivity corresponds to *learning by doing*. Achieving self-maintained growth assumes the acceptance of two postulates. Firstly, increasing a firm's stock of capital leads to parallel increase in its stock of knowledge. Secondly, each firm's knowledge is a collective good that can be accessed by any other firm for zero cost. In other words, once new knowledge has been discovered it is immediately disseminated in the economy. These two postulates are the basis for obtaining endogenous growth. This is possible if there is strict proportionality between the aggregate stock of physical capital and the stock of technological knowledge of the whole of the economy. If this is not the case, either there is no growth or growth is explosive. The probability that growth is truly endogenous is small then, and self-maintained growth is only one of a number of possibilities.

Other authors obtain endogenous growth models by assuming that various government actions have positive effects on the growth rate. These governmental activities include the supply of public infrastructure, protection of property rights and the levying of tax on economic activity. Barro (1990) introduces a new factor in the aggregate production function – public expenditure. Using Samuelson's (1954) classical approach to public goods, he assumes that the latter are indivisible and non-explosive. In fact, each firm benefits from all public expenditure, but their use by a particular firm does not decrease the quantity available for the others. The economy then displays endogenous

[11] Solow (1994, p. 53).

growth if – and only if – public expenditure increases with physical capital (since decreasing returns are neutralised). Endogenous growth is once again a special case. Indeed, achieving it depends on an "arbitrary" hypothesis.

II. Inventory of Empirical Evaluations

The considerable progress made in the theoretical modelling of knowledge has not really induced comparable progress at an empirical level [12]. The main reason is certainly the very nature of the concept of knowledge. Indeed, knowledge is not a good like the others; it must be measured in a different way and its relation to the price system modified in comparison to that of other goods. Nevertheless, the importance of knowledge and particularly education for economic growth has been evaluated in numerous empirical studies. Early work was carried out on the subject by Solow (1956 and 1957) and Denison (1962 and 1967). Their aim is measuring the contributions of the factors of production – generally capital and labour – and the increase of technical progress to the growth rate as a whole. Their work consists of residual analysis of the contribution of the total productivity of the factors. In this context, Denison (1962) demonstrates that the growth of the average level of education – evaluated by income differentials that can be ascribed to each level of education and measured using the average number of years of formal education – accounts for more than 20% of US growth from 1929 to 1957.

Subsequent empirical evaluation was focused on verifying the idea of at least conditional convergence of economies. Barro (1991) demonstrated in an article that in the period 1960-1985 the growth rate in a sample of 98 countries depended positively on the initial level of human capital measured by schooling rates and negatively on the initial level of per capita GNP. Convergence can thus be confirmed, since most poor countries tend to grow more rapidly than rich countries, but only for a given quantity of human capital.

Mankiw, Romer and Weil (1991), with an identical database (Summers and Heston, 1988) to that used by Barro (1991), confirm the conclusions of Solow's model (1956) on condition that the importance of human capital is recognised. They thus broaden Solow's model by introducing the accumulation of human capital measured by the rate of schooling. They conclude that differences in saving, education and population growth account for the differences in per capita income. Their model, which includes exogenous technical progress and decreasing returns on capital, better explains the international variations in output per person than the models of endogenous growth.

Barro and Lee (1993) have studied the rate of scholastic success in the adult population at various levels (uneducated, primary education, secondary educa-

[12] "Although there has been some progress in modeling knowledge at theoretical level, less progess has been made at the empirical level." Aghion and Howitt (1998, p. 435).

tion, higher education) from 1960 to 1985 in 129 countries and conclude that levels of education have considerable explanatory capacity. Education has direct positive effects on the growth rate of the GNP. In contrast, Benhabib and Spiegel (1994) maintain that the growth rate of human capital measured by the number of years of education of the working population does not significantly explain the growth rates of per capita output. However, human capital levels play a substantial role as determinants of increase in per capita income. It is therefore no longer possible to consider human capital as a factor of production, as this hypothesis implies that its growth rate and not its level accounts for the rate of increase of per capita income.

Like that of Jones (1995), this conclusion leads to doubting theories of endogenous growth. Indeed, Jones (1995) criticises endogenous growth models based on research and development activities: input (measured by the number of scientists and engineers engaged in R&D activity) has increased significantly without any visible effects on the growth of per capita output and on growth of productivity. He concludes that long-term economic growth is not affected by structural parameters, except for those generally considered as being exogenous. He thus returns to Solow's conclusions.

In short, the different evaluations lead to diverging conclusions, while none of them directly tests the endogenous growth hypothesis. The testing of a hypothesis is only acceptable if the latter is both a hypothesis and the result of a model, as is stressed by Romer (1990, p. S84).

However, we are currently attempting to test the hypothesis of endogenous growth through a study on the causality relations between knowledge and economic growth in West Germany from 1960 to 1989. M. Monteils is also formulating equivalent tests for the case of France as part of her doctoral thesis.

Conclusion

The literature on "new growth theories" is diverse in nature. However, the structure of the models is identical, with endogenous growth becoming possible after the introduction of a new accumulation factor whose results are at least constant. This factor makes it possible to compensate the decreasing returns of capital accumulation. Growth factors other than the traditional factors of capital and labour are modelled for the first time. However, it would seem that the results of the models depend very strongly on research hypotheses that have not yet been verified.

According to the thinking of Lucas, in particular, the source of economic growth lies in the unlimited accumulation of human capital. This boundless increase in human capital is based on major hypotheses of non-decreasing returns of technology and training and on the existence of externalities. In fact, in the long run and as in Uzawa's model, economic growth might just as easily be nil.

In the model category inspired by the work of Romer, economic growth is a function of research and development, the latter depending on the share of human capital allocated to the research sector. Accumulation of knowledge (innovations) forms the engine of growth and this accumulation can be unlimited because of the very nature of knowledge, which is a non-rival good with partially exclusive use. Nevertheless, self-maintained growth is based on the hypothesis of linear *A*. However, experience lends credibility to the thought that the opportunities in research do not diminish rather than affirming that the accumulation of human capital Shows non-decreasing returns.

The other models achieve self-maintained growth in an identical way by means of hypotheses concerning the non-decreasing returns of the new factors of accumulation. This fundamental criticism opens up considerable research prospects, in particular with regard to empirical verifications. The latter may either confirm the Endogenous growth hypotheses or, more simply, encourage a return to the Solowian tradition, since, *a priori*, there is nothing to prevent the inclusion of Education, research and development, public expenditure, etc. in the model defined by Solow in 1956.

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